Self-Filtering Solar Telescopes

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Measurements of the Sun's vector magnetic field carried out at MSFC have demonstrated that observations with better spatial, and temporal resolution, and over a wider spectral range, than can be achieved with ground-based telescopes, are required to meet our scientific objectives. Since ground-based telescopes are limited by the variability of the Earth's atmosphere, we are investigating concepts for moderate to large aperture (30- to 60-cm diameter), diffraction limited, spaced-based solar telescopes for operation in the visible and ultraviolet regions of the spectrum. Solar telescopes have unique thermal problems for they act as solar furnaces, focusing large amounts of energy onto the post primary optics. Past and future telescope concepts are usually based on either Cassegrain or Gregorian designs. In the Cassegrain, the secondary mirror is located inside the focal plane of the primary mirror, and the main advantage, for space applications is its compactness. In addition, the secondary mirror provides less central obscuration than the Gregorian design resulting in an improved modulation transfer function (MTF) at angular frequencies just above the diffraction limit. The disadvantage of the standard Cassegrain design is that there is no location for a field stop in the primary optical path. Consequently, the full solar flux, including both the infrared and ultraviolet, is focused onto the smaller secondary mirror. This increased flux creates thermal problems and enhances the potential for the polymerization of hydrocarbons on the mirror surface, which can result in a catastrophic loss of reflectivity. To solve this problem a full aperture prefilter with a bandpass defined by a simple metal[1] dielectric coating can reduce the thermal load on the telescope. This concept has been successfully employed on the MSFC vector magnetograph for the past 25 years. A disadvantage of the approach is that it limits the spectral bands that can be investigated to the visible and in particular excludes the far UV.

In the Gregorian design the secondary mirror is mounted outside the focus of the primary. This allows a field stop to be placed at the primary focus which can be used to limit the total energy striking the secondary mirror. Typically, the stop reduces the field of view to about 2 arc min^2 which results in less than half a percent of the Sun's total flux from reaching the secondary. Because the incident beam is not filtered, the Gregorian design provides access to the full solar spectrum and has applications where the emphasis is on ultra-high spatial resolution over a restricted field of view. The disadvantages of the Gregorian design is that the total length is approximately 30 percent longer than a Cassegrain with the same f-number and it has a larger central obscuration.

The scientific focus of the MSFC group is the study of how the Sun's magnetic field changes with time and how these changes lead to the explosive release of energy in solar flares. To satisfy these objectives the magnetic field observations have to be made over relatively large fields of view. Consequently, a Cassegrain with a full aperture prefilter has been our preferred design. However, as the diameter of the primary aperture increases the fabrication and support of a distortion free, full aperture prefilter becomes increasingly difficult if not impossible.

To overcome this difficulty, we have developed an approach which combines a modification to the design of the primary mirror with advances in thin film, dielectric, multilayer filters to develop a self-filtering Cassegrain telescope which eliminates the requirement for a full aperture prefilter. In this concept the transmission coatings which were previously applied to the prefilter are converted to reflective coatings[2] and applied directly to the front surfaces of the primary and secondary mirrors. The solar radiation incident on the primary is either reflected, if it is within the passband of the filters, or transmitted through the body of the mirror. Our modification is to figure the rear surface of the primary mirror and provide it with an all purpose reflective coating, such as silver, which has high reflectivity in the IR. In the ideal case, the curvature of this rear surface is such that the incident rays, following refraction in the glass, strike the surface normally and are reflected back along their original path and out of the telescope. This condition is met for parabolic surfaces when the radius of curvature of the rear surface is equal to the product of the refractive index and the radius of curvature of the front surface (fig. 167). In practice the refractive index is a function of wavelength and many of the reflected rays will have slight departures from the normal. Therefore, the figure of the back surface is designed to satisfy this condition in the IR so that rays at all shorter wavelengths will exit the primary mirror at angles that are outside the incident ray and consequently will not strike the secondary mirror. Two applications for this technology are under consideration. The first is for a space magnetograph to obtain improved measurements of the vector fields in the photosphere. The magnetically sensitive, spectral lines of interest are in the visible at 525.0 nm and 630.2 nm and the performance of a multiple bandpass filter, which also includes the Hα line at 656.3 nm is shown in figure 168 (b). The design which was prepared for Solar-B, a joint ISAS/NASA mission to measure solar magnetic fields, consists of an f-4 telescope system with a 0.5- to 0.6-m aperture primary mirror. The physical

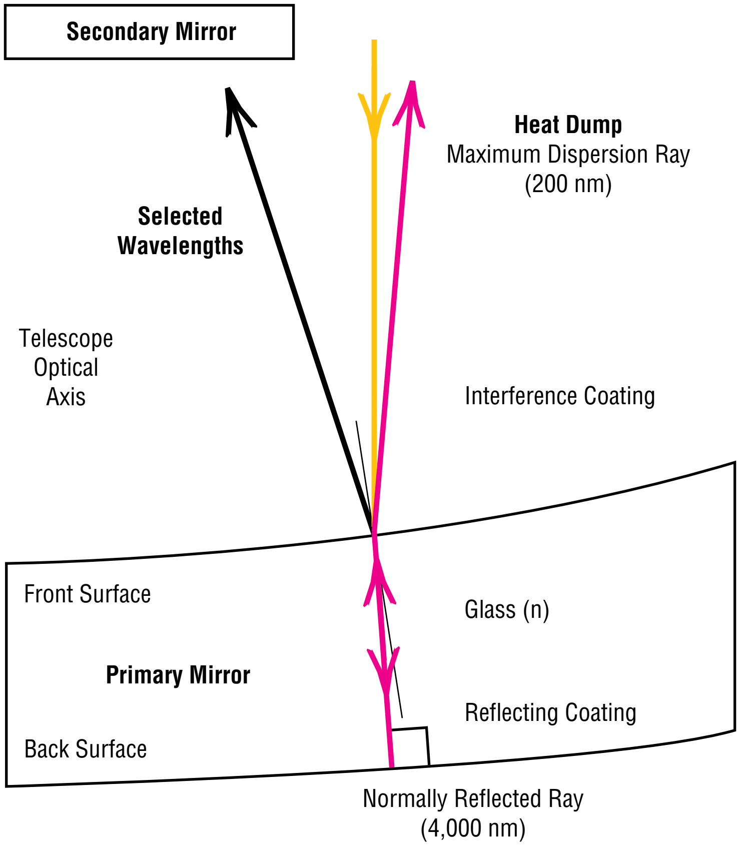

FIGURE 167.—Schematic of the self-filtering mirror concept.

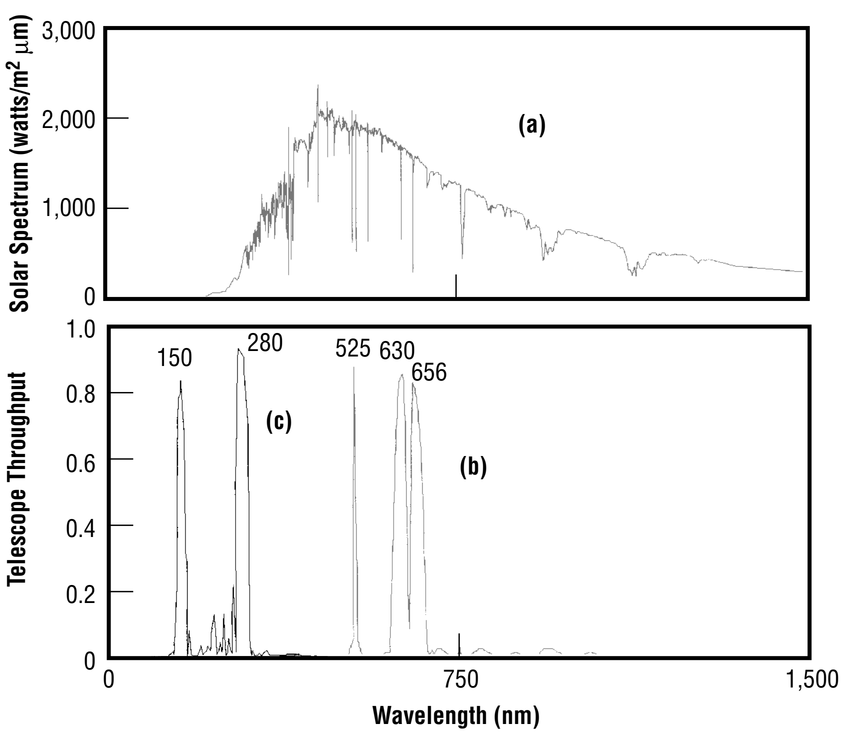

FIGURE 168.—(a) The solar spectrum (b) the passbands of the photospheric vector magnetograph (c) the passbands of the UV magnetograph.

envelope for the telescope provided by the spacecraft is extremely limited and the self-filtering Cassegrain design provides an elegant solution for this case.

The second application is for a vector magnetograph operating in the far-ultraviolet region of the spectrum. Lines in this region of the spectrum are formed at higher temperatures than the photospheric lines, observed in the visible, which in turn corresponds to greater heights in the solar atmosphere. By comparing the UV and visible measurements, an understanding of how the structure of the magnetic field varies with height can be gained. Such information is important because we believe that a significant part of the Sun's dynamic behavior originates in this upper chromo-sphere-low coronal region. The ultraviolet magnetograph that we are proposing for a suborbital flight opportunity will use the spectral lines of Mg II at 280 nm and CIV at 150 nm. These magnetically sensitive lines are formed in the upper chromosphere and low corona respectively and the measurement of their polarization will provide the first opportunity to observe solar vector magnetic fields in a region where the field lines are unconstrained by the solar atmosphere.

A preliminary design of this telescope has an f-10 system with a 0.3-m diameter primary. To obtain the bandpass performance shown in figure168 (c), a customized dielectric coating consisting of alternating layers of lanthanum fluoride and magnesium fluoride has been designed.

In both these applications practical reasons impose strict limits on the size of the instrument, a condition which is generally true for all space-based solar telescopes. For these situations, where high spatial resolution over wide field of view is also required, the self-filtering Cassegrain concept offers an elegant design solution.

[1]Brueckner, G.E.: "A New Completely Digitized Filter Magnetograph". IAV Symposium no. 43, Reidel: New York, p. 84, 1971.

[2]Zukic, M.; Torr, D.G.; Spann, J.F.; and Torr, M.R.: "Optical Constants of Thin Films". *Applied Optics*, vol. 29, p. 4284, 1990.

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University Involvement: University of Alabama in Huntsville

Biographical Sketch: John M. Davis received his Ph.D. in physics from the University of Leeds, UK in 1964. He has held positions at the Massachusetts Institute of Technology, and American Science and Engineering, Inc., Cambridge, MA, where the primary emphasis of his work was the design, development and testing of scientific, and especially x-ray imaging, instrumentation for space. He joined the Marshall Center as chief of the Solar Physics Branch whose members are involved in experimental and theoretical studies of solar magnetic fields and their interaction with the solar atmosphere.

G. Allen Gary received his Ph.D. in physics in 1969 from the University of Georgia. He is in the Solar Physics Branch at the Marshall Center, investigating the nature of coronal structures and solar magnetic fields. His research also includes the general study of the magnetic field's configuration, evolution, and morphology together with estimation of the energy content of active regions. His theoretical work involves developing models of linear and nonlinear force-free magnetic fields and electric currents in the solar chromosphere-corona.

Edward West received his B.S. degree in engineering science from Tennessee Technological University in 1973 and his M.S. degree in electrical engineering from the University of Alabama, Huntsville in 1982. He joined the Marshall Center in the fall of 1973 and has been associated with the Space Sciences Laboratory since that time. He has worked with the hardware and software development of both the original vector magnetograph and the breadboard design of a space-based instrument called the EXperimental Vector Magnetograph (EXVM). His main interests are in the development of high resolution, stable polarizing optics that can improve vector magnetic field measurements and in reducing the instrumental errors, both optical and electrical, so that a magnetic resolution of 50 gauss transverse can be achieved. Along with the development of new instrumentation to observe the vector magnetic field on the Sun, he is interested in developing the real-time analysis tools to predict flares, and in studying magnetic evolution and magneto-optic effects of the Sun.

Dr. Alan Shapiro is a coating physicist at the Optics and Radio Frequency Division at MSFC's Astrionics Laboratory. He conducts research on specialized optical coatings, many of which are utilized for astronomical and astrophysics related programs. He also conducts research on the surface morphology of material surfaces. Shapiro earned his Ph.D. in condensed matter physics from the University of Illinois, Urbana-Champaign in 1987, after which he worked at International Business Machine Corporation, East Fishkill, NY. He has worked for NASA at MSFC since May 1989.